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14. ABSTRACT

This TOP describes procedures for evaluating effects of sand and dust exposure on automotive systems or components of wheeled and tracked vehicles when operated in a dry off-road environment. Also included are procedures for testing stationary equipment that may be sited in a dusty environment. This method is particularly appropriate for dry regions environmental testing, since large amounts of dust become airborne due to wheel and track disturbance of the dry sand, silt, and clay soil that is characteristic of dry regions.

15. SUBJECT TERMS

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TEST OPERATIONS PROCEDURE

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SAND AND DUST TESTING OF WHEELED AND TRACKED VEHICLES AND STATIONARY EQUIPMENT

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*This TOP supersedes TOP 2-2-819 dated 15 February 2002.

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1. SCOPE.

a. This TOP addresses the requirements for testing automotive systems and related equipment in a sand and dust environment. This environmental condition, primarily found in dry regions, is described in U.S. Army Regulation (AR) 70-38[1], Research, Development, Test and Evaluation of Materiel for Extreme Climatic Conditions. AR 70-38 defines the extremes of environmental factors to which military materiel may be exposed and gives guidance for test levels. This regulation in combination with MIL-HDBK-310[2], Global Climatic Data for Developing Military Products, is the basis for this TOP.

b. This TOP addresses testing of equipment and vehicles exposed to elevated dust levels due to military operations. Exposure to ambient dust levels, without military operations is not addressed, nor is testing of items used in close proximity to aircraft operating (transit or hovering) over dry terrain addressed. Exposure during three types of operations is considered:

(1) Performance of the vehicle and/or equipment on the vehicle in sand and dust, a system- or subsystem-level test.

(2) Performance of engine air cleaners and other filters.

(3) Stationary equipment and other end items used in areas near operating surface vehicles.

It should be noted that it is common for a system-level sand and dust test to also include testing of the air cleaners and other filters.

In the early stages of development of an automotive system or stationary equipment there may be components and sub-systems that need to be tested for suitability to operate in dust before final prototypes are available for end item or system-level testing. At this stage of development, component or subsystem level tests should be conducted within a closed chamber in accordance with MIL-STD-810[3], Environmental Test Methods, Method 510, Sand and Dust. Tests of larger items can be tested in accordance with TOP 1-2-621[4], Outdoor Sand and Dust Testing.

Testing in accordance with MIL-STD-810, Method 510, or TOP 1-2-621 does not include functional operation during active testing. Additionally, testing by using either of these two documents is generally conducted with milled silica that replicates a specific particle size distribution (PSD) but not the complex chemical compositions found in naturally occurring dust.

2. FACILITIES AND INSTRUMENTATION.

This section addresses dust testing of tracked vehicles and wheeled vehicles that are underway, either with or without a lead vehicle, and stationary items located near operating surface vehicles. Tests are conducted on natural soil in dry, dusty conditions.

2.1 Facilities.

Item	Requirement
Dust course	Fairly level, straight, and smooth surface of desert pavement, known as gravelly undissected piedmont, uniformly mixed surface (usually accomplished using a crawler tractor pulling a disk harrow), 10-15 cm deep; low moisture content (depending on time of year), 4 percent by volume maximum.
Level cross-country course	Unprepared course traversing washes, gravelly dissected piedmont, sandy plains and bills, and moderate grades of short duration.
Gravel course	Prepared natural surface covered with small-sized gravel; fairly level, with minimum grades of medium duration.

2.2 Instrumentation.

The following parameters are required for all three scenarios discussed in this document except for the last device; it is for engine air cleaner testing only.

Devices for Measuring	Permissible Measurement Uncertainty(see NOTE 1)
Time	±1 second
Road speed (speedometer)	0 - 50 kph: ±0.5 kph 0 - 100 kph: ±1.0kph 0 - 200 kph: ±2.0 kph
Engine speed (transducer)	0 - 3,000 rpm: ±5 rpm 0 - 6,000 rpm: ±10 rpm
Pressure	±1 percent full scale at any value
Engine oil pressure	±3 kPa
Meteorological conditions: Ambient temperature Relative humidity Wind speed Wind direction Barometric pressure	 ±2 °C ±2 percent relative humidity ±3 kph ±10 degrees ±4 mBar

Devices for Measuring	Permissible MeasurementUncertainty(see NOTE 1)
Soil moisture content	±0.1 percent measured by weight change upon drying of sample
Concentration of airborne dust: Vacuum pump Flow meter Measurement of dust mass	 ±2 percent ±4 percent ±0.0005 g
Weight of air cleaner element	±0.5 percent (Total estimated error is ±5 percent after including effects of moisture and other factors. See Appendix C, paragraph 3.3)

Note 1: Measurement accuracy for instrumentation is the two-sigma value for normal distribution; so the stated tolerances should not be exceeded in more than one measurement of 20.

3. REQUIRED TEST CONDITIONS.

3.1 Facilities and Equipment for Vehicle System Tests.

CAUTION

Ear protection must be used by all those exposed to the dust cloud for more than a few moments to keep dust from building up in the ear.

a. Ensure that the ground surface has been disked and that the moisture content is 4 percent or less.

b. Ensure that the following are available for use, in serviceable condition, and calibrated:

(1) Test vehicle operator breathing apparatus.

The test vehicle operator must be provided with breathable air clear of dust and associated hazardous materials. The system used to provide this must be clean and functional before testing can begin. Disposable facemasks do not adequately seal and must not be used by any operator working in the dust cloud. A helmet with a sealed visor, an over-the-shoulder shroud sealed to the bottom of the helmet, and a clean, cooled, pressurized air-feed is required to keep dust from entering the operator’s lungs. An inspection of the system before use for any air or cooling system leaks must be performed. It must be ensured that the set-up in the test vehicle allows the operator free movement of arms and head. The visor must be clear of foreign material and scratches. A communications headset must be fitted to the operator’s ear before the helmet is donned. The chinstrap or other securing device must be properly fastened.

(2) The lead vehicle in convoy testing must be equipped with bright lights mounted on the rear of the vehicle and high enough on stanchions to be visible to the trail vehicle operator. Colored streamers should also be attached to the stanchions for increased visibility. The test vehicle should be equipped with a streamer or flag to improve the lead vehicle driver's awareness of the test vehicle position. All these must be inspected before each run begins.

(3) Install a high-capacity dry-filter air-sampling system, including provision of replacement sampling filters and plastic bags for transport (See Appendix C for discussion of proper placement of samplers; also see Appendix D, Example of Dust Sampling Equipment).

(a) Install the No. 1 sampler (all samplers should be set to a flow rate that is isokinetic) on the front of the vehicle, in the center of the grill or windshield, or the center of the front of the vehicle. The sampler should be level, with the opening oriented toward the direction of vehicle travel.

(b) Samplers for equipment should be mounted into the direction of airflow. For personnel locations, the samplers should be mounted with the inlets pointed upward and the airflow set to a minimal intake to simulate regular breathing patterns. Initiate recording of test time upon start of vehicle operation.

(4) Weighing apparatus for filter samples.

(5) Compressed air supply pressure regulator and pressure gauge.

(6) A particle size analyzer to determine the size of the particles in the dust sample.

(7) Laboratory procedure for determining soil sample moisture content (or apparatus for this analysis).

(8) Laboratory procedure and apparatuses for determining contaminants and wear materials in fluid samples.

c. Check the test vehicle to ensure:

(1) The engine and power train components have been serviced, including the brakes.

(2) The tire pressure or track tension is properly adjusted.

(3) Test items on the vehicle are in proper working order.

(4) Initial sample set of vehicle fluids and lubricants. These should be processed to determine a baseline for wear metal analysis and silicate contamination.

d. In addition to the aforementioned requirements, the following are required for engine air cleaner testing:

(1) Ensure that the following are available for use and are in serviceable working condition and/or calibrated:

(a) Air cleaner element weighing apparatus.

(b) New plastic bags, with weights marked on them, used to transport air cleaner elements that have reached maximum restriction.

(c) Nozzle or tubing with a maximum inside diameter of 3.175 mm (⅛ inch) for use in blowing dust from the air cleaner element.

(2) Check the test vehicle to ensure:

(a) Adequate engine air cleaner elements and crew area ventilation filters are available to support the test vehicles in order to minimize down time for vehicle maintenance.

NOTE: It is recommended that at least two spare particle filters per each component (e.g. engine air, crew air, etc) be available during testing.

(b) All air intake ducting are serviceable.

(c) All air intake ducting are clean beyond the filter element.

(d) All air intake duct clamps are serviceable and tight.

(e) The air cleaner canister is securely mounted and serviceable (including clamps).

(f) The air cleaner canister and filter element may be easily removed without interference from hoses, etc.

(g) All air system gaskets and seals are present and properly seated.

(3) Check the new air filter elements for visible defects.

(a) Check condition of the primary element gasket.

(b) Check the filter carefully to ensure that it has not been damaged, including air filter media, and inner and outer screens.

3.2 Facilities and Equipment for Testing Stationary Materiel.

For testing stationary materiel located near operating surface vehicles on natural soil in dry, dusty conditions, an electrical generator or a refueling station for example, the test item should be located in the center of a flat open area of sufficient size to allow a support vehicle to drive a circular path of minimum radius around the test item. Also ensure the following are accomplished.

a. The ground surface has been disked and that the moisture content is 4 percent or less.

b. The following are available for use and in serviceable working condition and calibrated:

(1) Soil sample moisture determination apparatus.

(2) High-capacity dry-filter air-sampling system, including replacement sampling filters and plastic bags for transport (See Appendix D, Example of Dust Sampling Equipment).

(3) Disk to prepare the surface of the dust course.

(4) Compressed air supply pressure regulator and pressure gauge.

(5) A particle size analyzer to determine the size of the particles in the dust sample.

3.3 Environmental Factors.

Stop all testing when any of the following environmental conditions are exceeded:

a. Maximum wind speed, 20 kph (12 mph).

b. Maximum relative humidity, 60 percent.

c. Minimum ambient temperature, 13 °C (55 °F).

d. Maximum moisture content of dust, 4 percent.

NOTE: Factors of wind speed, wind direction relative to course direction, relative humidity, ambient temperature, moisture content of the dust and dust cloud particle concentration must also be considered collectively as to their impact on the test. Engineering judgment must be used to determine if the test conditions are adequate to continue the test.

3.4 Other Factors.

Ensure the following:

a. All equipment checks are satisfactory. If there are any discrepancies, correct them before starting test.

b. All instrumentation devices are calibrated.

c. The instrumentation list specifies the installed location or method.

d. The test item configurations to be tested are identified.

e. Those item-particular controls critical for achieving accurate and reproducible test results have been determined.

f. The operator knows how to use the respirator system.

g. All signals to be used for communicating between the test director and the operators are briefed and are clearly understood by all.

h. A radio check between the operators and the test director is completed.

4. TEST PROCEDURES.

4.1 Pre-Operation Procedures.

a. System and Subsystem Testing.

(1) A maintenance inspection of the test vehicle with special attention to the test items must be performed to ensure that the vehicle and test items are in good working order before testing. Any discrepancies must be maintained at this time. The results will be compared to the post-test inspection results to determine degradation of the test items and correct discrepancies found on the test vehicle.

For each component testing, establish a baseline of function in accordance with established TOPs prior to any operation on the dust course. These results can be compared to further tests performed at interim points during the test, and after completion of the dust test, or as specified in the test plan. For example, prior to the start of the dust test perform a laying and tracking performance test on the vehicle gun-control system in accordance with TOP 3-2-603, Gun Control Systems (Vehicular). Then contrast the results to the same laying and tracking test sequence completed during the dust test, and post-test for possible change or degradation in performance.

(2) Take an oil sample from the engine and transmission of the test vehicle. Oil samples should also be taken at the end of each day regardless of the cycle duration. The results must be obtained and reviewed before the next day's run begins (see Appendix C). Samples of other key system fluids (e.g. hydraulic fluid) should also be taken at this time.

(3) Record the test bed vehicle odometer and hour meter reading.

(4) Document the condition of the vehicle interior, exterior, and all equipment of interest in the test by photograph and written description.

(5) Take soil samples to ensure that soil moisture content is less than 4 percent. At the end of each day that proceeds any day of dust testing, collect nine 100-gram samples from the dust course. Samples should be taken from three locations equally spaced around the course at depths of 0 (surface), 75, and 150 mm (0, 3, and 6 inches). Soil moistures should be assessed by the oven-dry method, ASTM D 2216-90[6]. Weigh each sample, heat at 110 °C (230 °F) for 12 hours, cool in a desiccator, and reweigh.

(6) Conduct a safety briefing before operations commence each day and before conducting any activity that is different than was briefed earlier in the day.

b. The following procedures need to be followed for engine air cleaner testing.

(1) Take an oil sample from the engine and transmission of the lead vehicle and test vehicle. Oil samples should also be taken at the end of each day regardless of the cycle duration. The results must be obtained and reviewed before the next day's run begins (see Appendix C).

(2) Install a new, clean air cleaner element in the lead and test vehicles just before starting the test to allow maximum uninterrupted running time. For the test vehicle, ensure that the clean air cleaner element is weighed and recorded. Record both the government National Stock Number (NSN) and the manufacturer's part number of the test element.

(3) Determine the initial air cleaner restriction at maximum air demand. This may result from engine operation at high stall (transmission in high range, brakes applied, and full throttle for 4 to 5 seconds), or the restriction can be measured with the engine at high idle speed, or at full-throttle acceleration.

NOTE: The air restriction lags engine speed; maximum rpm may need to be held in order to provide an accurate reading.

(4) Install the air-sampling system (See Appendix C for discussion of proper placement of samplers). Initiate recording of test time upon start of vehicle operation.

(a) Install the No. 1 sampler (all samplers should be set to a flow rate that is isokinetic) on the front of the vehicle, in the center of the grill or windshield, or the center of the front of the vehicle. The sampler should be level, with the opening oriented toward the direction of vehicle travel.

(b) The rest of the exterior samplers should be mounted toward the oncoming airflow. Mount one sampler in the air stream entering the air intake.

(6) Document the condition of the engine air cleaner and the ducting before the air cleaner and after by photographs and written description.

c. For stationary equipment performance testing:

(1) Document the condition of the test item exterior and all equipment of interest in the test by photograph and written description.

(2) Record the test item hour meter.

(3) Take an oil sample from the engine and transmission of the dust generating vehicle and test item. Oil samples should also be taken at the end of each day regardless of the cycle duration. The results must be obtained and reviewed before the second day's run is begun (see Appendix C). Take samples of other system fluids (e.g. hydraulic fluid) as appropriate.

(4) Take soil samples.

(5) Install air-sampling system (See Appendix C for discussion of proper placement of isokinetic samplers). Initiate recording of test time upon start of equipment operation.

(a) Install the No. 1 sampler near the test equipment, 1.2m above ground level and 0.5m away from the equipment. The sampler should be mounted vertically with the opening pointed up.

(b) All other samplers should be mounted near test equipment or at personnel positions, according to test requirements. Samplers should be mounted vertically with the opening pointed up. Samplers placed at crew positions should be mounted at head level, vertically with the opening pointed up.

(6) Conduct a safety briefing before operations commence each day and before conducting any activity that is different than briefed earlier in the day.

4.2 Operational Procedures.

a. System and Subsystem Testing.

(1) Operate the test bed vehicle over the dust course at constant speed or according to the test plan, either with or without a lead vehicle, depending on test requirements and expected vehicle use. If the vehicle is to be tested using a lead vehicle, testing should be first performed without the lead vehicle to establish a baseline of dust test performance for the test items. The use of a lead vehicle represents traveling in a column, in convoy on unpaved desert roads or trails, or in a column through a minefield. Testing with a lead vehicle is commonly referred to as the convoy configuration; testing without a lead vehicle is referred to as the non-convoy configuration.

(2) Operate the test vehicle at a safe speed.

(3) When in convoy mode, operate the test vehicle, using appropriate safety precautions, in the densest portion of the dust cloud produced by the lead vehicle, if applicable.

(4) Depending on the type of vehicle and equipment being tested, elements to monitor closely for safety or proper function may be, but not limited to:

(a) High restriction across the engine air cleaner element resulting in loss of power.

(b) Engine temperature.

(c) Plugged crew ventilation air filter.

(d) Health concerns such as obscured goggles, breathing of elevated levels of PM 10 (airborne particles $\leq 10\mu m$ in diameter) material compared to U.S. Department of Labor Occupational Safety and Health Administration (OSHA) Directive CPL 03-00-007[7], National Emphasis Program - Crystalline Silica or other standards.

(e) Malfunctioning (leaking) hydraulics.

(5) Other items to check periodically, but not limited to, are:

(a) Turret rotation (performance).

(b) Brake condition.

(c) Worn windshield or vision blocks.

(d) Obscured electronic displays, obscured gauges, obscured warning decals, obscured control identification, obscured indicator light or warning light identification.

(e) Obscured or shorted fire sensor resulting in malfunction of the fire suppression system.

(f) Malfunction in electronic controls or radios due to shorting or overheating.

(g) Malfunctioning (leaking) hydraulics.

(h) Hatch seal and other seal interference.

(i) Central Tire Inflation System, if present.

(j) Compressed Air System.

(k) Seized fan bearings, belt tension, and idler bearings.

(l) Plugged radiator resulting in an overheated engine.

(m) Plugged air conditioner condenser or evaporator resulting in loss in effectiveness or failure of the air conditioner.

(n) Obscured vision devices (periscopes/night vision systems/weapon sights).

(o) Starter performance.

(6) Record test time.

(7) Make notes pertinent to vehicle and sub-system operation.

(8) Continue operations until the specified mileage, time, or other criteria are attained that describe an operational cycle.

(9) Perform comparative tests as described in paragraph 4.1a.

(10) Document the condition of the vehicle interior, exterior, and all equipment of interest in the test by photograph and written description.

b. Engine air cleaner testing.

(1) Operate the test vehicle over the dust course at constant speed or according to the test plan, either with or without a lead vehicle, depending on test requirements and expected vehicle use. If the vehicle is to be tested using a lead vehicle, testing should be performed first without the lead vehicle to establish a baseline of dust test performance for the vehicle and its systems.

(2) Record the air cleaner restriction while the vehicle is underway.

(3) Depending on the type of vehicle being tested, elements to monitor closely for safety or proper function may be:

(a) High restriction across the engine air cleaner element resulting in loss of power.

(b) Plugged radiator resulting in an overheated engine.

(c) Plugged air conditioner condenser or evaporator resulting in loss in effectiveness or failure of the air conditioner.

(d) Plugged crew ventilation air filter.

(e) Turret rotation (performance).

(f) Seized fan bearings, belt tension, and idler bearings.

(g) Worn brakes.

(h) Worn windshield or vision blocks.

(i) Health concerns such as obscured goggles, breathing of elevated levels of PM 10 (airborne particles ≤ 10μm in diameter) material compared to U.S. Department of Labor Occupational Safety and Health Administration (OSHA) Directive CPL 03-00-007 or other standards.

(j) Malfunctioning (leaking) hydraulics.

(3) Continue operations until the specified mileage or other criteria are attained that describe an operational cycle, or until the air cleaner restriction attains the recommended maximum, or a significant power loss (when it becomes a problem to continue at the required speed) has been observed.

(4) In the case of a clogged filter:

(a) Determine the air cleaner restriction at maximum air demand. This may result from engine operation at high stall, or the restriction can be measured with the engine at high idle speed, or at full-throttle acceleration.

(b) Turn off the air sampler system and remove the air sample filters. Return each filter to the plastic bag used to transport the filter.

(c) Record test vehicle odometer and hour meter reading.

(d) Remove the engine air cleaner element, taking care not to loosen any dust from the element.

(e) Check the air cleaner element for damage. Insert the element into the previously weighed plastic bag.

(f) Inspect the air intake for dust beyond the air cleaner seals.

(g) Save any dust in the air cleaner canister for samples as required, but do not place this dust in the bag with the plugged element, and do not use it in the calculations to determine element weight gain.

(h) Weigh the air cleaner element and the bag together.

(i) Take a sample of dust from the exterior of the air cleaner element.

(j) Clean the air cleaner element according to the instructions contained in the vehicle technical manual, using the on-vehicle equipment specified. Do not substitute shop equipment for on-vehicle equipment. If the technical manuals do not prescribe a procedure, request one from the materiel developer. If a procedure cannot be obtained due to the developmental nature of the item, proceed as follows:

(a) Remove the air cleaner from the plastic bag and rap it against the palm of the hand to dislodge the larger particles. Continue this until visible evidence of particle dropping has ceased.

(b) Using a compressed air source of not more than 700 kPa (100 psi), blow the dust from the air cleaner using a nozzle not larger than 3.2 mm (1/8 inch). Do not hold the nozzle in direct contact with the element. Direct the air first against the inside of the element, then against the outside of the element.

NOTE: The cleaning time should not exceed the time allotted for crew services and checks specified in the requirements documents. If no such times are specified, do not exceed 20 to 30 minutes for vehicles with single air cleaner elements.

(k) Weigh the cleaned element then reinstall it.

(l) Record the required air cleaner element data.

(m) Determine the air cleaner restriction at maximum air demand. This may result from engine operation at high stall, or the restriction can be measured with the engine at high idle speed, or at full-throttle acceleration.

(5) If possible, document the condition of the air cleaner and ducting before and after the air cleaner by photographs and written description.

c. For stationary equipment performance testing:

(1) Operate the dust-generating vehicle at constant speed sufficient to maintain dust conditions in proximity of the test item using appropriate safety precautions.

(2) Record test time.

(3) Operate the test items at the time intervals specified in the test plan. Make notes pertinent to their operation.

(4) Depending on the type of test item, elements to monitor closely for safety or proper function may be:

(a) High restriction across an engine air cleaner element resulting in loss of power.

(b) Plugged radiator resulting in an overheated engine.

(c) Seized fan bearings, belt tension, and idler bearings.

(d) Obscured electronic displays, obscured gauges, obscured warning decals, obscured control identification, obscured indicator light or warning light identification.

(e) Malfunction in electronic controls or radios due to shorting or overheating.

(f) Malfunctioning (leaking) hydraulics.

NOTE: To assist in preventing damage to hydraulically functioned items, operate the hydraulic equipment periodically throughout the test, or as described in the test plan.

(5) Continue operations until the specified number of hours or other criteria are attained that describe an operational cycle, or until a significant function loss has been observed.

(6) Document the condition of the equipment interior (where possible) and exterior by photographs and written description.

4.3 Post-Operation Procedures.

a. System and subsystem testing.

(1) Turn off the air sampler system and change the air sample filters. Return each filter to the plastic bag used to transport the filter.

(2) Record test bed vehicle odometer and hour meter reading.

(3) Perform vehicle function checks as described in paragraph 4.1. Document any operational or functional problems.

(4) Visually inspect all test items for dust related problems and document findings. Function test items as required.

(5) Photograph dust accumulation on all test items, and of any erosion or unusual adhesions of the surface of the test items.

(6) Take oil samples from, but not limited to, the engine, transmission, transfer case, power steering, hubs of the test vehicle, see paragraph 3.1c. (See Appendix D for specific laboratory tests).

(7) Document the condition of the vehicle interior, exterior, and all equipment of interest in the test by photograph and written description.

(8) Perform a limited technical inspection (LTI), or maintenance planned in the test plan, to assure that all systems and the test vehicle are in good working condition. Maintenance of items that were damaged during testing can be performed at this time.

b. Engine air cleaner testing.

(1) Turn off the air sampler system and change the air sample filters. Return each filter to the plastic bag used to transport the filter.

(2) Record test vehicle odometer and hour meter reading.

(3) Remove the engine air cleaner element, taking care not to loosen any dust from the element.

(4) Check the air cleaner element for damage. Insert the element into the previously weighed plastic bag.

(5) Inspect the air intake for dust beyond the air cleaner seals.

(6) Save any dust in the air cleaner canister for samples as required, but do not place this dust in the bag with the plugged element, and do not use it in the calculations to determine element weight gain.

(7) Weigh the air cleaner element and the bag together.

(8) Take a sample of dust from the exterior of the air cleaner element.

(9) Clean the air cleaner element according to the instructions contained in the vehicle technical manual, using the on-vehicle equipment specified. Do not substitute shop equipment for on-vehicle equipment. If the technical manuals do not prescribe a procedure, request one from the materiel developer. If a procedure cannot be obtained due to the developmental nature of the item, proceed as follows:

(a) Remove the air cleaner from the plastic bag and rap it against the palm of the hand to dislodge the larger particles. Continue this until visible evidence of particle dropping has ceased.

(b) Using a compressed air source of not more than 700 kPa (100 psi), blow the dust from the air cleaner using a nozzle not larger than 3.2mm (1/8 inch). Do not hold the nozzle in direct contact with the element. Direct the air first against the inside of the element, then against the outside of the element.

(10) Weigh the cleaned element then reinstall it.

(11) Record the required air cleaner element data.

(12) To determine the air filter stabilized operating time from recleaning to maximum restriction, repeat the test cycle (paragraph 4.2 above) for approximately 3 to 4 cleaning cycles, depending on the rate of filter dust loading.

(13) Document the condition of the air cleaner and ducting, before and after the air cleaner, by photograph and written description.

c. Stationary equipment testing:

(1) Turn off the air sampler and change the air sample filters.

(2) Record the test item hour meter or the dust-generating vehicle hour meter.

(3) Document any operational or functional problems that may be caused by dust.

(4) Visually inspect the test item for dust related problems and document findings. Operate the test item as required.

(5) Photograph dust accumulation on the test item and of any erosion of the surface of the test item.

(6) Take an engine and transmission oil sample of the dust-generating vehicle and from the test item, see paragraph 4.1c. See Appendix D for specific laboratory tests.

(7) Document the condition of the test item interior (where possible) and exterior, by photographs and written description.

5. DATA REQUIRED.

5.1 Pretest.

a. System and subsystem testing.

(1) Results of equipment inspections, checks, and calibrations to include system and subsystem performance checks (See paragraph 4.1a. above).

(2) Test item configuration.

(3) Course used.

(4) Test area soil moisture content.

(5) Hour meter reading.

(6) Photographs and written description of the condition of the test item.

b. Engine air cleaner testing.

(1) Initial weights of new air cleaner elements.

(2) Initial weights of new plastic bags used to transport air cleaner elements that have reached maximum restriction.

(3) Manufacturer's or technical manual recommended maximum value for air cleaner restriction or other specified limiting conditions.

(4) Results of equipment inspections, checks, and calibrations.

(5) Test vehicle configuration.

(6) Course used.

(7) Course soil moisture content.

(8) Hour meter reading.

(9) Results from oil analysis.

(11) Photographs and written description of the condition of the test item.

c. Stationary equipment testing:

(1) Results of equipment inspections, checks, and calibrations to include system and subsystem performance checks.

(2) Photographs and written description of the condition of the test item exteriors.

(2) Test item hour meter or dust-generating vehicle hour meter.

(3) Test item configuration.

(4) Course used.

(5) Course soil moisture content.

(6) Photographs and written description of the condition of the test item.

5.2 <u>During Operation</u>.

a. System and subsystem testing:

(1) Note component operation or problems as appropriate, for example, temperatures, pressures, binding linkage, etc. Document results of system and subsystem checks.

(2) Photographs of the test being performed. Also photographs of the test items when possible.

(3) Meteorological data.

(a) Ambient temperature.

(b) Relative humidity.

(c) Wind speed.

(d) Wind direction.

(e) Barometric pressure.

(4) Flow rate of air samplers.

b. Engine air cleaner testing:

(1) Meteorological data.

(a) Ambient temperature.

(b) Relative humidity.

(c) Wind speed.

(d) Wind direction.

(e) Barometric pressure.

(2) Flow rate of air samplers.

(3) Air cleaner restriction as a function of time.

(4) Engine speed as needed to estimate engine airflow during test.

(5) Photographs of the test being performed and when the vehicle is stopped.

(6) Results from engine operation at high stall.

(7) Filter weights.

e. For stationary equipment performance testing:

(1) Record of the test item hour meter.

(2) Documentation of any operational or functional problems that may be caused by dust.

(3) Results of visual inspections of the test item for dust related problems. Results of operation of the test item.

(4) Photographs of dust accumulation on the test item and of any erosion of the surface of the test item.

5.3 After Each Cycle.

a. System and subsystem testing :

(1) Elapsed operating time of test item.

(2) Test vehicle odometer and hour meter reading.

(3) Record and describe malfunctions or problems caused by dust accumulation or erosion.

(4) Results from performance checks of test items performed.

(5) Photographs taken.

(6) Results from oil sample analysis.

b. Engine air cleaner testing:

(1) Elapsed operating time of test vehicle.

(2) Test vehicle odometer and hour meter reading.

(3) Malfunctions or problems caused by dust accumulation or erosion.

(4) Restriction across the engine air cleaner during high stall.

(5) Engine speed at high stall restriction.

(6) Photographs taken.

(7) Results from oil sample analysis.

c. For stationary equipment performance testing:

(1) Record the test item hour meter or the dust-generating vehicle hour meter.

(2) Document any operational or functional problems that may have been caused by dust.

(3) Document results of visual inspection of the test item for dust related problems..

(4) Photographs of dust accumulation on the test item and of any erosion of the surface of the test item.

(5) Result from engine and transmission oil sample of the support vehicle and from the test item, see paragraph 4.1c. See Appendix D for specific laboratory tests.

5.4 After Completion of Dust Testing.

a. System and subsystem testing:

(1) Elapsed operating time of test item.

(2) Test vehicle odometer and hour meter reading.

(3) Reason for cycle termination, if any.

(4) Results from final function/performance operations.

(5) Results from maintenance inspection.

(6) Results from laboratory analysis of fluid samples.

(7) Photographs taken.

b. Engine air cleaner testing:

(1) Elapsed operating time of engine air cleaner.

(2) Test vehicle odometer and hour meter reading.

(3) Reason for cycle termination, if any.

(4) Results from maintenance inspection.

(5) Results from laboratory analysis of fluid samples.

(6) Engine air cleaner data:

(a) Final restriction across the engine air cleaner.

(b) Engine speed at final restriction.

(c) Weight of dust in air cleaner canister.

(7) Air cleaner element data:

(a) Weight of the element before and after cleaning.

(b) Cleaning method.

(c) Cleaning time.

(d) Evidence of damage to filter.

(8) Photographs taken.

c. Stationary item testing:

(1) Record of the test item hour meter or dust-generating vehicle hour meter.

(2) Documentation of any operational or functional problems that may have been caused by dust.

(3) Results from maintenance inspection.

(4) Photograph dust accumulation on the test item and of any erosion of the surface of the test item.

(5) Results from fluid samples.

(6) Condition of filter exterior and interior.

(7) Documentation of any dust contamination of the system.

(8) Documentation of seal integrity.

5.5 Laboratory.

In the laboratory, document the following for all testing:

a. A wear metal analysis of pretest, daily, and posttest engine oil samples for each cycle (Appendix D).

b. For each cycle, a particle size analysis of the dust from:

(1) Air sampling apparatus.

(2) Settled dust on or adjacent to individual test items, if called for in test plan or requested by customer.

c. The average dust concentration in the air at sampling locations for each cycle.

d. The moisture content of soil samples at the end of each day.

e. For engine air cleaner testing, the following data need to be collected along with paragraphs 5.5.a through 5.5.d.

(1) Particle size and shape of dust samples collected from the air cleaner element exterior.

(2) Particle size and shape of dust samples collected from the air cleaner canister interior.

(3) Particle size and shape of dust samples in the air cleaner ducting beyond the air cleaner (if dust is found there).

(4) The average dust concentration in the air at sampling locations for each cycle.

6. PRESENTATION OF DATA.

6.1 Narrative Format.

Present the following in narrative format:

a. Test procedure, course or test area used, and test item configuration.

b. Functional problems of the vehicle or its subsystems caused by dust contamination.

c. Problem areas or potential problem areas due to dust accumulation.

d. Summary of results.

e. For engine air cleaner testing, the following data need to be reported along with paragraphs 6.1.a through 6.1.d.

(1) Operating time (total, convoy, non-convoy, run time to each test stoppage, run time to reach maximum air cleaner restriction). See Appendix C, paragraph 4.3 for normalizing test results.

(2) Miles accrued (total, convoy, non-convoy, run mileage to each test stoppage, run mileage to reach maximum air cleaner restriction).

(3) Air cleaner restriction during operations at each stoppage, at the end of each operating cycle, and at each stop due to reaching maximum air cleaner restriction.

(4) Time required to clean filter.

(5) Weight (clean, dirty, and net gain) for each air cleaner element used during the test. Indicate if the dirty air cleaner element was removed due to maximum air cleaner restriction reading. If removed for maximum restriction, include the weight before and after cleaning.

(6) Inspection for damage.

(7) Average engine speed.

(8) Specific dust density comparison of sampler data at areas of critical dust exposure such as at the engine air cleaner intake (see Appendix C, paragraph 4.3, Comparative Analysis Between Similar Tests).

6.2 Tabular Format.

Present the following in tabular format:

a. Weight gain summary of filters.

b. Results of initial equipment checks.

c. Laboratory analysis of all air, soil, dust, and engine oil samples.

d. Meteorological data.

(1) Ambient temperature

(2) Relative humidity

(3) Wind speed

(4) Wind direction

(5) Barometric pressure

e. Vehicle and system data.

(1) Operating time

(2) Miles accrued

(3) Run mileage to each test stoppage

(4) Comparative results from equipment performance tests done before, during, and after the dust test.

6.3 Graphical Format.

Present the following in graphical format:

a. Air cleaner restriction vs. run time for each cycle. See Figure 1 for example.

b. Air filter weight gain for each run and clean cycle. See Figure 2 for example.

c. Particle size distribution for each sample taken. See Figure 3 for example.

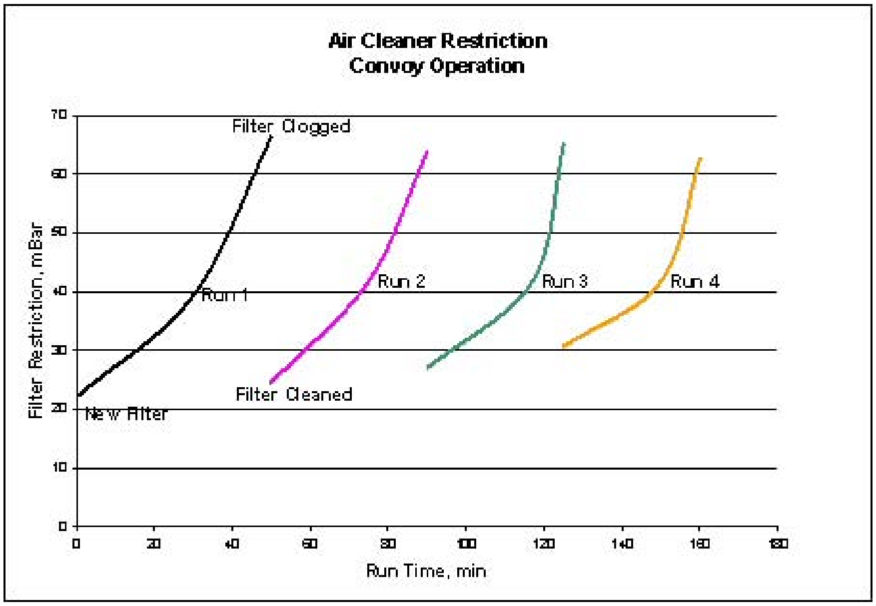

Figure 1. Example Plot of Air Cleaner Restriction vs. Run Time.

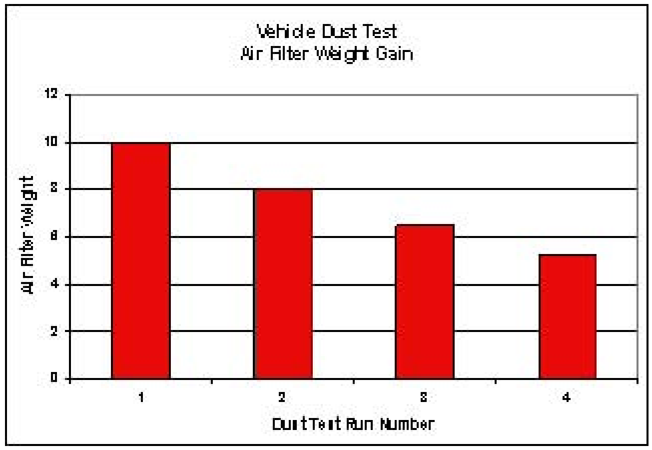

Figure 2. Example Plot of Air Filter Weight Gain.

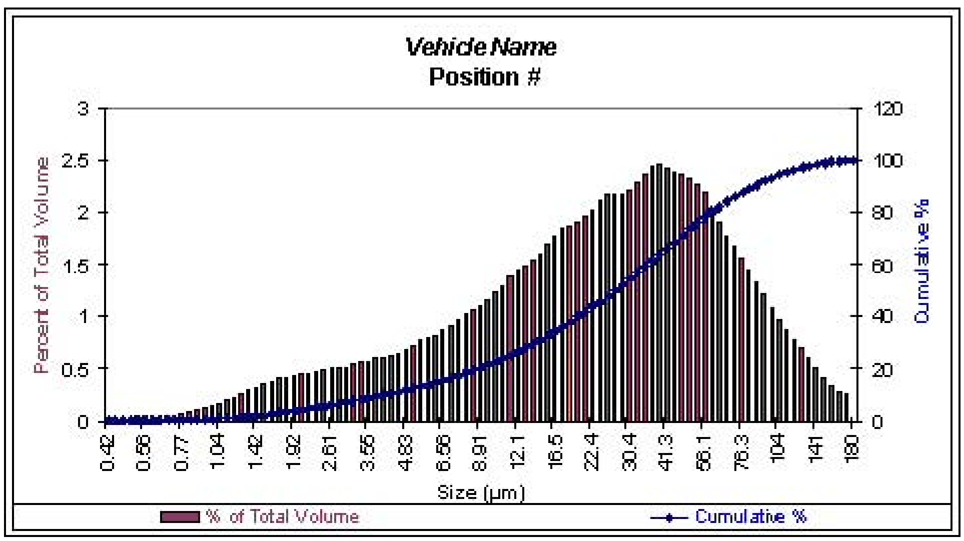

Figure 3. Example Plot of Particle Size Distribution of Dust Sample.

APPENDIX A. OIL SAMPLE LABORATORY TESTS.

Parameter	**Units**	**Engine**	**Transmission**	**Transfer Case**	**Power Steering**
Sulphated Ash	percent				
Viscosity Index					
Viscosity at 40ºC	CS				
Viscosity at 100ºC	CS				
Aluminum	ppm				
Boron	ppm				
Chromium	ppm				
Copper	ppm				
Iron	ppm				
Lead	ppm				
Magnesium	ppm				
Molybdenum	ppm				
Nickel	ppm				
Silicon	ppm				
Silver	ppm				
Sodium	ppm				
Tin	ppm				
Titanium	ppm				
Zinc	ppm				
Fuel Dilution	percent				
Carbon Residue Percent	percent				
Water Content	Percent by volume				

REMARKS:

APPENDIX B. TYPICAL SAMPLE DATA SHEET.

Date: ________________________

Vehicle Type: ________________

Vehicle Reg. No: ______________

Course: ______________________

Vehicle Weight: _______________

Lead Vehicle Used (yes or no): ___

Gear Range Used: _____________

Vehicle Configuration: ____

____

Element Starting Weight: ____

Element Weight Before Cleaning: ____

Element weight After Cleaning: ____

How Element Cleaned: ____

Cleaning Time: ____

Time	Odometer	Eng. Speed	Air Cleaner Restriction	Air Sampler Flow Rate	Remarks/Other Data

APPENDIX C. BACKGROUND DISCUSSION OF PROBLEMS IN DUST MEASUREMENT INCLUDING RATIONALE FOR TEST CONDITIONS.

1. General Comments.

Testing in the natural environment always has less control on variables than testing under laboratory conditions. This is especially true when non-homogeneous factors are involved, such as terrain or dust, as opposed to more homogeneous factors such as air temperature. Variation of test results is to be expected. The reason for testing in the natural environment is to allow all factors to have their effect. A laboratory environment, although otherwise excellent, may leave out a critical factor or, probably even more common, neglect an interaction between factors that would yield results that predict unexpected performance in the natural environment. The downside of dust testing in a natural environment is that the specific dust production vs. time may not be comparable on similar tests, for example, the effect of 4 hours of dust testing now may not be comparable to 4 hours of dust testing last year. The best way to control the variables is to understand some of the physical principles of the measurement process and the management of environmental variables.

2. Dust Measurement.

Dust from the natural environment as well as laboratory standard dust such as International Organization for Standardization (ISO) Coarse and ISO Fine that is used in laboratory air filter dust tests, is a mixture of particles of different sizes and composition. Even if the dust is initially uniformly mixed when the dust is dispersed in air, or other media, the individual particles will have different characteristics based on their size and composition.

Unless the air being drawn into the sampler is traveling at exactly the same direction and speed as the air in the environment, the kinetic energy of the particles will not allow a change in direction or speed. The result is an inaccurate reading in the dust loading and dust composition of the sample.

In the dust test environment, a close approximation to the “same speed, same direction” technique known as “isokinetic” sampling should be used. This is the result when the direction and speed of the airflow around the sample area of the test vehicle is matched by the average speed of the airflow into the sampler. Done properly, the direction of the dust particles in the moving air should not be diverted enough to matter from their initial path and will flow into the sampler to result in the same dust density, composition, and particle size distribution as in the air being sampled. The three examples below illustrate some common problems in sampler application.

In the following simplified diagram (Figure C-1), the first example shows a misdirected sampler that is perpendicular to the airflow. The larger particles cannot be turned fast enough and do not enter the sampler. The sample will therefore show a bias toward the characteristics of the smaller particles.

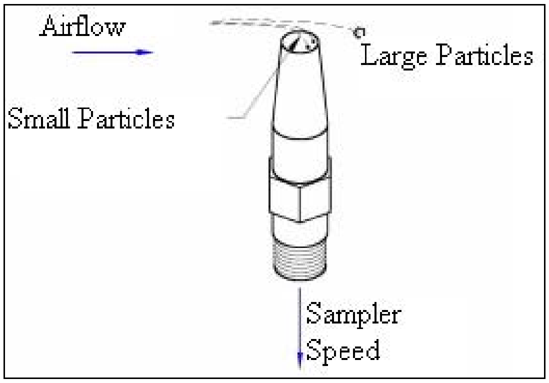

Figure C-1. Sampler Perpendicular to Airflow

In the second example, Figure C-2, the speed of the dust-laden air is faster than the airflow of the sampler. The result is that the larger particles directed at the sampler intake have a greater chance of entering the sampler then adjacent smaller particles, which will more likely follow the airflow to the outside. The sample will therefore show a bias toward the characteristics of the larger particles.

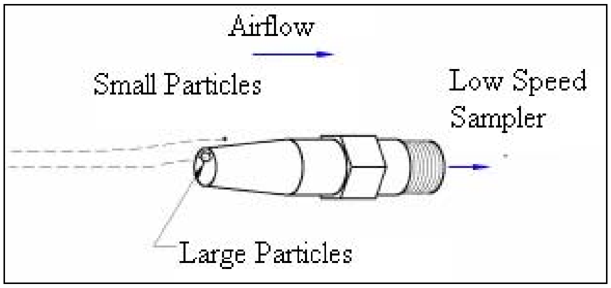

Figure C-2. Low Speed Sampler

In the last example, Figure C-3, the speed of the dust-laden air is slower than the airflow rate of the sampler. So now the smaller particles directed toward outside the sampler intake, but near the edge, are pulled into the sampler while the adjacent larger particles are more likely to follow the airflow to the outside. This time the sample will show a bias toward the characteristics of the smaller particles.

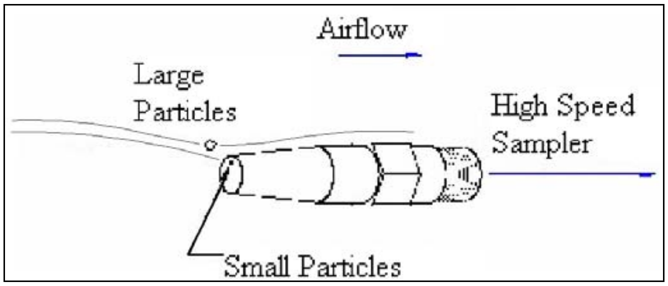

Figure C-3. High Speed Sampler

3. Rationale for Selected Test Constraints.

3.1 Humidity.

The limit of 60-percent relative humidity (RH) is based on the fact that in high relative humidity air, material, especially highly porous material such as soil, will tend to absorb water. This absorption of water also applies to dust particles dispersed into the air. The presence of absorbed water is known to change suspended particle characteristics and increase agglomeration (clumping) of dust particles. At high moisture conditions, dust would no longer be produced. The 60-percent RH constraint is considered reasonable. At humidity levels higher than this, most materials begin to have significant equilibrium moisture content. In the desert environment, the 60-percent RH limitation imposes only a little constraint since this condition would normally only occur during high humidity periods in the early morning hours, or during time of rain. The highest monthly average RH at Yuma Proving Ground (YPG) is 43 percent in December with a maximum of 61 percent and a minimum of 26 percent.

3.2 Temperature.

Temperature by itself is probably not strongly and directly linked to dust production factors. However, temperature is directly linked to other factors that do affect dust production. Low temperatures are directly associated with high relative humidity and periods of low solar radiation. Both high RH and low solar radiation make it difficult to dry out the dust test courses if they become wet and increase the equilibrium moisture content when dried out. Since at YPG the coldest month has an average maximum of 19 °C (66 °F), the limit of 13 °C (55 °F) only restricts testing during morning hours in mid-winter. The temperature limit forms a simple rule to eliminate unfavorable, but uncharacterized, test conditions.

3.3 Filter Weight Accuracy.

The accuracy of ±5 percent for filter weight accuracy was chosen for the following reasons: Air cleaner element weights are within ±1 gram in 22.65 kg, however, the moisture content of the dust can be as high as 4 percent. Do not dry the filter elements to correct for moisture. In addition, part of the dust "cake" may be lost when the filter element is removed from the vehicle for weighing. Five percent error of measurement is reasonable to expect when all system errors are considered.

4. Test Course Variability.

The general factors which affect dust production and dust loading have been discussed previously. These include: Airflow speed and direction; relative humidity; soil moisture content; and test vehicle speed. The test vehicle speed can be controlled and the other factors measured. There are, however, other test course surface conditions that are not easily measured or characterized and can have an effect on dust production. These surface conditions arise because of various physical mechanisms.

4.1 Initial Test Course Condition.

Depending on the initial moisture content of the ground, driving over the soil surface will both force particles to pack together and will also break clumps apart. At high moisture levels the first predominates and at low moisture levels the latter predominates. When the soil is wetted or if undisturbed for a long period, the soil will tend to agglomerate and even form a solid, although weak, crust. The purpose of the disking is to break up this crust and make the soil more uniform. Disking, however, does not do a complete job of breaking apart the agglomerated particles. For this reason the dust production can actually increase with mileage during initial operation as the vehicles "pulverize" the agglomerated particles. Anecdotal evidence indicates that the dust level can double from the first to the third day of testing. For this reason it may be appropriate to have the lead (non-test) vehicle make repeated passes over the test course prior to the conduct of the test. Re-disking the test course during a test series is sometimes done to smooth ruts. Anecdotal evidence indicates that this re-disking brings the agglomerated material back to the surface and reduces the dust production.

4.2 Continued or Excessive Use.

A countervailing effect that occurs if the dust course is used repeatedly and heavily during an extended period is a reduction of dust loading with mileage. The most common explanation for this effect is due to the wind blowing the fine dust off of the course. It is also possible in some cases that it is a human factors effect because the trailing vehicle must be deliberately driven in an environment where visibility is very poor, there is a possibility of colliding with the lead vehicle, and the environment is physically uncomfortable. Fatigue would also tend to make the driver "back-off."

4.3 Comparative Analysis between Similar Tests.

Regarding the previous discussion of test conditions that affect test results, it is too simplistic to say that the results will be more consistent if these variables are more tightly controlled. The independent variable in dust tests is generally the time of the test cycle. Since the current dust measurement system does not allow real-time monitoring of the dust loading, the test results tend to be reported as a function of run time. This may be okay for certain data presentations, but to compare dust performance of one system to another, the data must be equated to the specific dust exposure of one of the vehicles using the analysis process of Comparative Run Time. A key element in making this analysis is locating the No. 1 sampler at the recommended position at the front of the vehicle; 1.2m above the road surface, 0.5m in front of the vehicle, and centered from side to side. This ensures that the concentration of the airborne dust presented to the vehicle is not greatly influenced by the aerodynamics of the vehicle.

To calculate the Comparative Run Time, multiply the vehicle's run time by the ratio of the dust concentrations collected from the No. 1 samplers of the two vehicles. The Comparative Run Time can then be directly compared to the actual run time of the other vehicle.
To compute the Comparative Run Time the following formula applies:

$$ComparativeRunTimeB = RunTimeB \times \frac{DustConcentrationB}{DustConcentrationA}$$

Example: Compare the performance of air cleaners on two vehicles tested on the dust course at different times, and with different vehicle operators. Vehicle A was able to operate until the standard engine air filter clogged after 4 hours of running. The average dust density from the No. 1 sampler was 4.0g/m^3. Vehicle B, with a modified engine air filtration system, operated for only 3.5 hours when the filter finally clogged, and the average dust density from the No. 1 sampler was 4.8g/m^3. To compare run-time performance of vehicle B to that of vehicle A, compute the Comparative Run Time of vehicle B:

$$ComparativeRunTimeB = 3.5hr \times \frac{4.8g/m^3}{4.0g/m^3} = 4.2hr$$

Therefore, by computing the Comparative Run Time of vehicle B, the estimated performance of the modified engine air cleaner of vehicle B was better by 0.2 hr compared with the standard engine air filter of vehicle A, or 0.2 hr ÷ 4 hr x 100 = 5 percent.

5. An Alternate Method of Dust Measurement.

Because of foregoing factors which affect test accuracy, it is always good to have an alternate method of measuring critical factors. It is sometimes not possible to measure the parameter of interest directly, as in this case, the dust concentration in the air is inferred rather than directly measured. For the determination of the dust concentration to be accurate, the individually measured parameters-dust sample weight and mass airflow-must be accurately measured. The advantage of alternate measurements that use different physical principles is that if the test conditions invalidate the precision for one method, it may not have the same effect on the other. The alternate measurement methods can act as a crosscheck on each other.

5.1 Direct Collection on Filter Element-No Precleaner.

In this case, all of the air used by the engine in the test vehicle passes through the air cleaner element. For vehicles not using a self-cleaning element, the dust from the air is accumulated on the filter element for the entire test period. In this simple case, the dust collected on the element is all of the dust that was in the air prior to the air being consumed by the engine. Therefore, the average dust concentration is simply the total dust collected, divided by the total air consumed by the test vehicle engine.

Although the engine airflow is not normally directly measured, it can be correlated with engine speed that can be accurately recorded (see paragraph 5.3 below). Dust concentration measured by this method is an alternate measure of average dust concentration in the engine air intake during the test. It should be noted, however, that this value can be different from the dust levels outside of the air inlet for the reasons discussed in paragraph 2.2.

5.2 Direct Collection on Filter Element-with Pre-cleaner.

This is similar to the previous case except a pre-cleaner reduces the dust loading of the air going to the engine. Since there is generally no way to collect the dust removed by the pre-cleaner, the dust concentration measured by the previous technique (paragraph 5. 1) is still a valid alternative to estimate the dust concentration of the airflow AFTER the pre-cleaner. However, the actual dust concentration is radically reduced from the dust concentration of the air to the pre-cleaner by the efficiency of the pre-cleaner. If an estimate of the pre-cleaner efficiency can be obtained (either from the developer or by comparison to similar units), the original dust concentration can be estimated. Although the accuracy of this method is considerably reduced from the no-pre-cleaner method, the results can be used to detect major problems with other dust level measurements.

5.3 Engine Intake Airflow Formula.

This formula can be used to approximate the maximum engine intake air volume flow rate at maximum engine speed. In the formula, the following units are used:

QMAX = Maximum air volume flow rate, m^3/min

VD = Total engine displacement volume, liters

SMAX = Maximum engine speed, rpm

VE = Volumetric efficiency

Naturally Aspirated Diesel Engines, VE = 0.85

Turbocharged diesel Engines, VE = 1.60

Turbocharged diesel engine with aftercooler, VE = 1.85

$$QMAX = VD \times SMAX \times VE$$

APPENDIX D. EXAMPLE OF DUST SAMPLING EQUIPMENT.

1. Physical Sampling

The most common method of measuring dust concentration in extreme-high dust density air involves drawing a representative sample of air collecting and measuring the dust from that sample. This involves pulling a measured amount of air through a dry media filter.

2. High Capacity Dry Filter Concept

A high capacity dry filter sampling system was developed at YPG (Figure D-1). The system uses a sampling tip with filters of moderate diameter, about 10cm (Figure D-2). In-house experiments indicate that with appropriate filter media this filter can accumulate large quantities of sand and dust (100 grams) without excessive flow restriction. This is sufficient to operate continuously for a typical test period without reducing airflow or sampling period. Each sampling circuit uses a separate flow control (Figure D-3) and air pump (Figure D-4) for maximum stability and balance of the system.

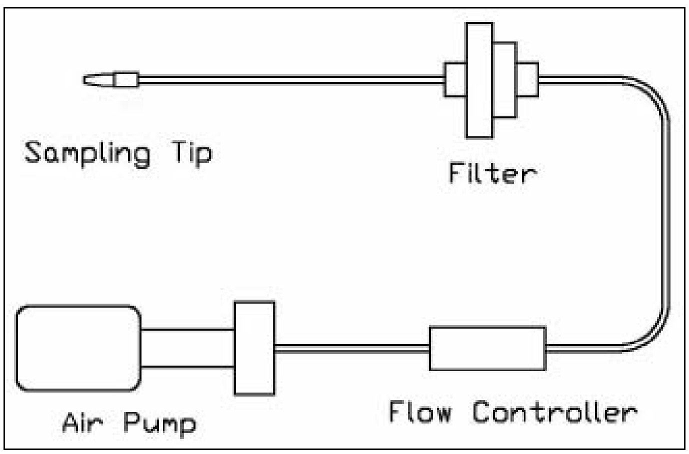

Figure D-1. High Capacity Dry Filter System.
(One Shown of a Multiple System)

Flow controllers are mass flow meters (using thermal principles) in combination with computer-controlled valves. These controllers can accurately maintain specific flow through each filter independently and will compensate for any change in flow restriction, pump speed, etc. High capacity dry filters have also been shown to reduce the variance in sample flow to an acceptable level.

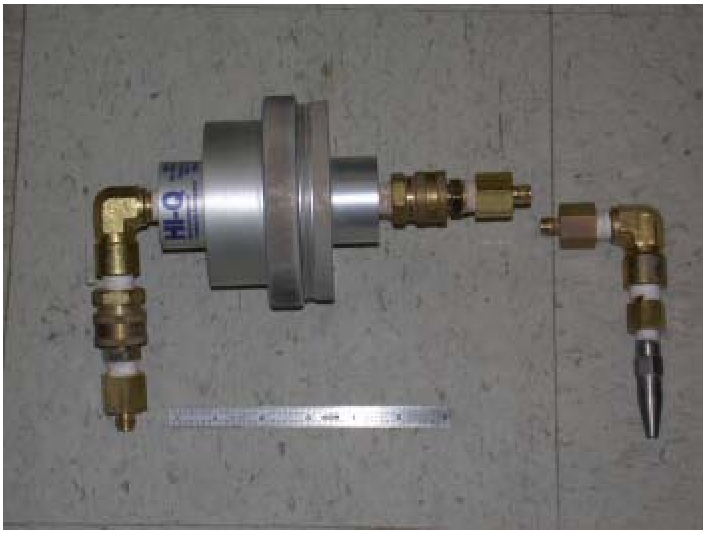

Figure D-2. Filter Holder and Probe.

Figure D-3. Datalogger and Mass Flow Regulators.

Figure D-4. Vacuum Pumps.

APPENDIX E. ABBREVIATIONS.

AR	-	U.S. Army Regulation
ASTM	-	American Society for Testing and Materials
C	-	Celsius
cm	-	centimeter
g	-	gram
ISO	-	International Organization for Standardization
kPa	-	kilopascal
kph	-	kilometer per hour
km	-	kilometer
m	-	meter
mBar	-	millibars
mm	-	millimeter
MIL-HDBK	-	Military Handbook
MIL-STD	-	Military Standard
min	-	minute
No.	-	number
NSN	-	National Stock Number
OSHA	-	Occupational Safety Health Administration
Psi	-	pound per square inch
rpm	-	revolutions per minute
TOP	-	Test Operations Procedure
YPG	-	U.S. Army Yuma Proving Ground

APPENDIX F. REFERENCES.

1. U.S. Army Regulation (AR) 70-38, Research, Development, Test and Evaluation of Materiel for Extreme Climatic Conditions, 15 September 1979.

2. Military Handbook (MIL-HDBK) 310, Global Climatic Data for Developing Military Products, 23 June 1997.

3. Military Standard (MIL-STD) 810 G, Method 510, Environmental Engineering Considerations and Laboratory Tests 31 October, 2008.

4. Test Operation Procedure (TOP) 1-2-621, Outdoor Sand and Dust Testing, 05 March 2009.

5. TOP 3-2-603, Gun Control Systems (Vehicular), 13 August 1976.

6. American Society for Testing and Materials (ASTM) D 2216, Method for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass, 1 March 2005.

7. U.S. Department of Labor Occupational Safety and Health Administration (OSHA) Directive CPL 03-00-007 - National Emphasis Program - Crystalline Silica, 27 January 2008.

Forward comments, recommended changes, or any pertinent data which may be of use in improving this publication to the Test Business Management Division (CSTE-DTC-TM-B), U.S. Army Developmental Test Command, 314 Longs Corner Road, Aberdeen Proving Ground, MD 21005-5055. Technical information may be obtained from: Commander, U.S. Army Yuma Proving Ground, ATTN: CSTE-DTC-YP, 301 C St, Yuma, AZ 85365-9498. Additional copies are available from the Defense Technical Information Center, 8725 John J. Kingman Rd., STE 0944, Fort Belvoir, VA 22060-6218. This document is identified by the accession number (AD No.) printed on the first page.